3. ANALYSIS ALGORITHM

Channel occupancy was determined by making a sweep of the railroad land mobile radio service band with a spectrum analyzer. The measurement system sampled the frequency band from 160.208-161.572 MHz at approximately 1-s intervals. The sweep time over the frequency band was 620 ms with 1001 points or bins recorded per sweep. When a signal that exceeded a certain threshold was measured in a channel, a channel was considered occupied during that time. The channel usage was then determined by the total number of times that the channel was occupied divided by the total number of sweeps.

The message lengths were determined by detecting a signal in a channel on successive sweeps. For example, if there was no signal in a given channel on a sweep, but if a signal was detected in that channel during the next sweep, then it was determined that a message had started. If this signal was also present for six subsequent sweeps and then was not there on the seventh sweep, this was considered a single message of seven sweeps long (the first sweep plus the six subsequent sweeps). Since each sweep is approximately 1 s in length, this message would be approximately 7 s long.

An example of a spectrum analyzer trace is shown in Figure 11. This figure shows the noise and signals from several channels.

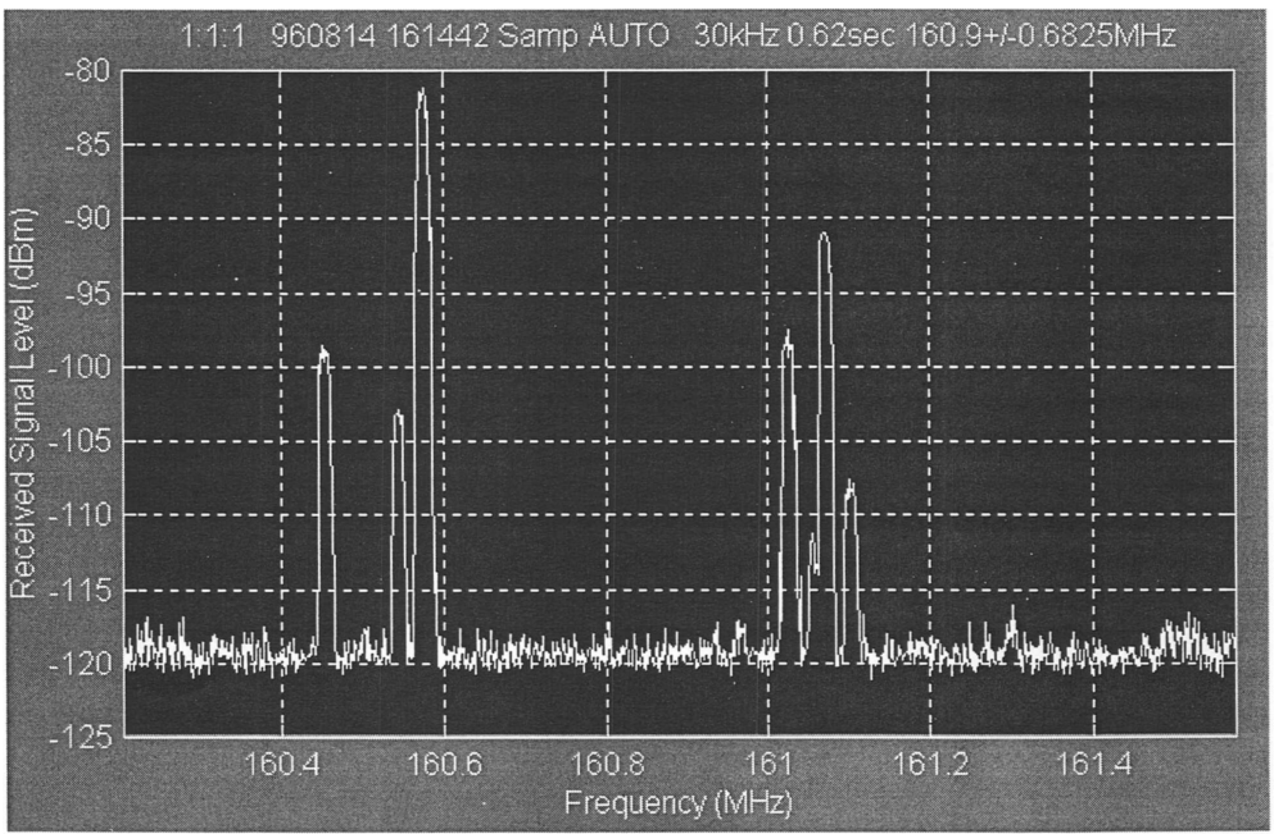


Figure 11. A typical spectrum analyzer trace from a site.

3.1 Noise Reduction Algorithm

To reduce the chances of noise giving a false indication that the channel was being used, the following issues were addressed:

1. To be considered a real signal, the measured level must exceed a signal threshold. The signal threshold was determined by measuring the mean noise power over a 24-hour period and selecting a threshold approximately 6 dB above the mean noise level.

2. In our analysis, the threshold appeared to eliminate most false signals due to noise when the mean value of the noise floor remains constant. Signals from transmitters weaker than the threshold were not counted in the analysis.

3. To ensure that the channel was occupied by a real signal and not impulsive noise, several measurement bins of the channel were evaluated. Each channel is 15-kHz wide and each channel occupies about eleven bins of the 1001 measurement bins swept by the spectrum analyzer. If the center bin contained a signal above the threshold, the two bins on either side of the center were also checked to ensure that their levels were above the threshold as well. If not, the channel was determined to contain noise, and not a signal.

3.2 Data Analysis

The raw data that were collected at the three different sites were processed to obtain message length statistics, channel utilization, band usage, median message length, and mean message length. These statistics can be calculated for any part of the day for an arbitrary time period.

On all of the figures that show the processed data from the different sites, there is a nominal value of one added to the number of messages for each message length. This was done because a log-log scale was used to show more information. This value however, was added just prior to plotting the results, so it does not affect any of the other statistics shown. Each of the figures have a time factor and band usage. The time factor is a correction to the value of the message lengths to obtain the actual times of each message. Because it was not possible to have the measurement system sweep at precisely 1-s intervals, this time factor is the average time of each sweep in seconds. The band usage is the cumulative utilization of each channel divided by the number of channels in the band. That is, it is the average channel utilization for the band.

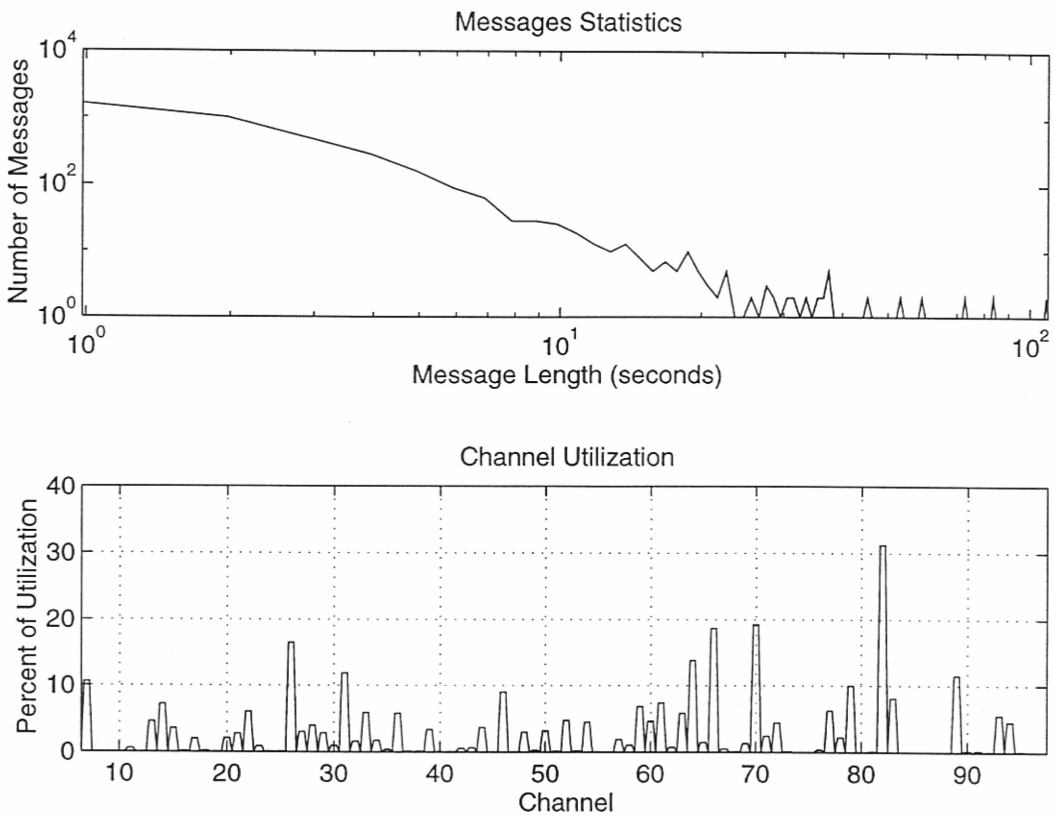
Figure 12 shows a 1-hour time period for Chicago, Illinois. All 91 channels were scanned for signals, yet this figure shows that there were some channels that were not used during this particular 1-hour period. Because of that, there is a high confidence that the signals detected are real and that they are not false indications generated by noise or other artifacts.

One of the objectives was to evaluate diurnal variations. Obtaining diurnal statistics on the traffic was difficult because of the continuous way the data was collected, stored, and processed. However, 1-hr blocks could be evaluated during different parts of the day. The data taken at the Chicago site were examined closely for any diurnal effects. Based on the small sample size, it appeared that there was a diurnal effect caused mainly by extra traffic being generated during the normal work day. This radio traffic could be attributed to commuter train traffic and “8 to 5” track force workers. Traffic roughly doubles during the normal work hours. Figure 13 shows an hour when the traffic is noticeably lower during the day and Figure 14 shows an hour when the traffic is noticeably higher during the day. These two figures show roughly a 300% difference in traffic since Figure 13 shows the least busy hour for a 24-hour period and Figure 14 shows the busiest hour for that 24-hour period.

Besides evaluating diurnal effects, another objective was to investigate message length characteristics to determine whether they are indicative of the type of traffic being sent on a particular channel. Certain channels primarily carry either voice or data traffic. When these channels are analyzed individually, they show characteristics that would indicate that these channels are indeed carrying a specific type of traffic. For the data channels, we did not expect the traffic to contain any messages that are very long because packet sizes should be relatively small. For the voice channels, we did expect the traffic to contain some messages that are substantially longer than the average. Figure 15 shows analysis results for a channel used for data transmission, and Figure 16 shows analysis results for a channel used for voice transmission.

In Figure 15, the messages are all under 10 s in duration. The reason for some of the longer messages is probably due to the resolution of the measuring system. The measuring system can only sample a channel approximately once per second. It is, therefore, possible for a message to be transmitted and terminated and another message started before the measurement system looks at that channel again. To the measurement system, that signal would be counted as the same message. In Figure 16, there are some messages that are very long—on the order of 100 s. We know from voice traffic over the telephone that there can be some very long conversation times, much longer than the average.

The three different sites had some subtle differences between them. One of the differences that is not seen in the analysis is the average noise floor. The average noise floor varied slightly from site-to-site and affects the minimum threshold selected. Other variations are the channels that are used and the percent utilization of a given channel. The message length statistics, however, had a tendency to follow a straight line when the number of messages of a given message length were plotted on a log-log scale. Figures 17, 18, and 19 show measurement results over a typical day’s worth of activities for Kansas City, Saint Louis, and Chicago, respectively.



Measurement Location: Chicago Channels 7 – 97

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz End Freq.: 161.572 MHz

RBW: 30kHz Detector: Sample Sweep time: 0.62 Sec. Points: 1001

Data Directory: F:\DATA\

First record: F:22 R:78 Number of records: 3660

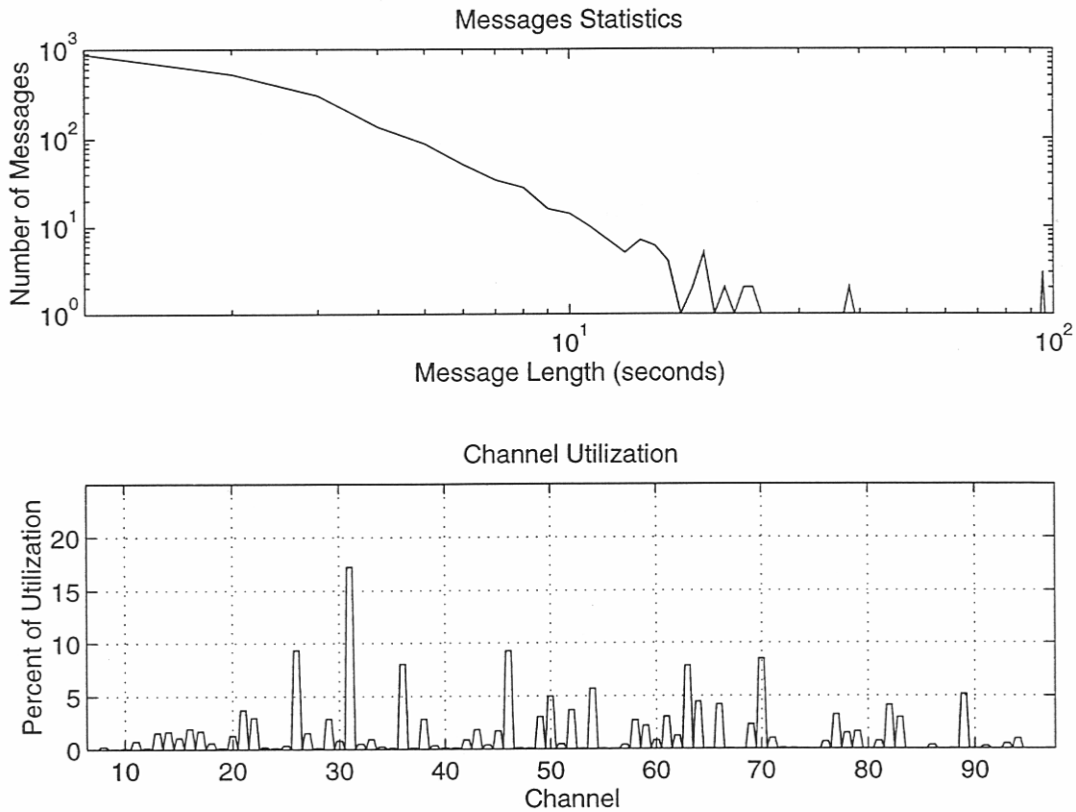
Measurement Start: 960814 (YYMMDD) 170000 (HHMMSS)

Measurement End: 960814 (YYMMDD) 180000 (HHMMSS)

Time factor: 0.9836 Band usage: 3.304% Threshold: –111dBm

Median Message Length: 1.967 Mean Message Length: 2.772 Total Number of Messages: 3904

Figure 12. Measurement results for a 1-hr time period at the Chicago, Illinois site.



Measurement Location: Chicago   Channels 7 – 97

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz   End Freq.: 161.572 MHz

RBW: 30kHz   Detector: Sample   Sweep time: 0.62 Sec.   Points: 1001

Data Directory: F:\DATA\

First record: F:427 R:98   Number of records: 3594

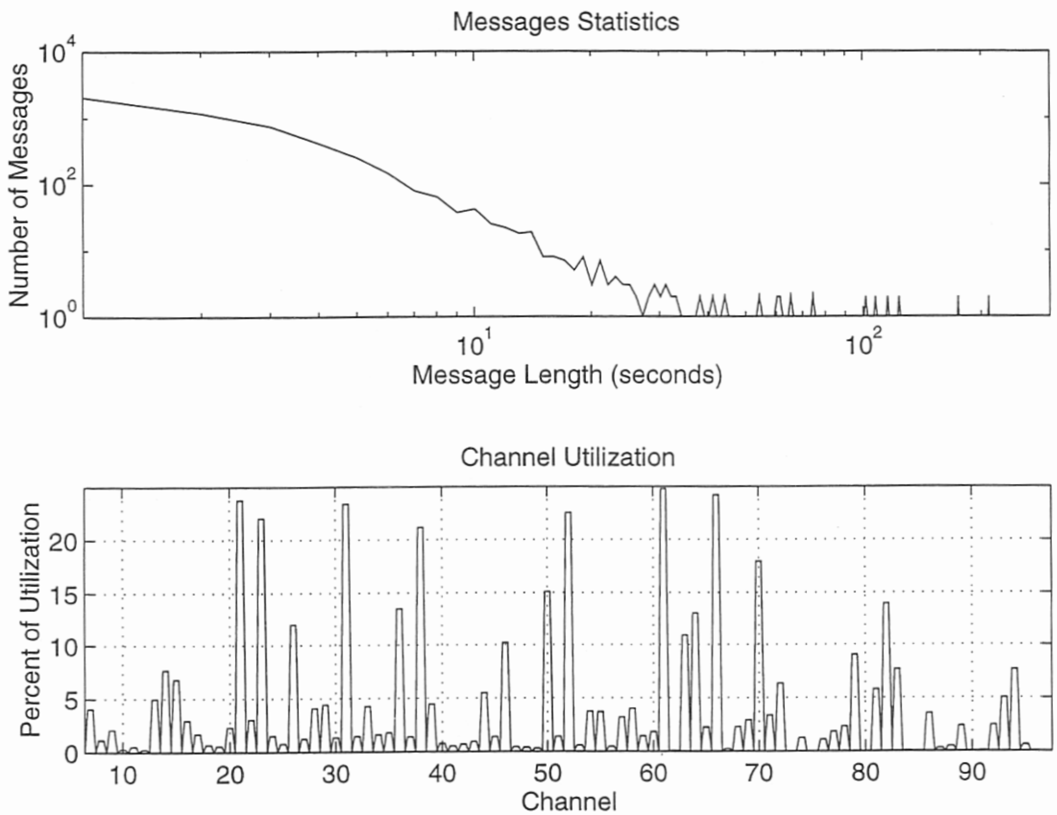
Measurement Start: 960816 (YYMMDD) 60000 (HHMMSS)

Measurement End: 960816 (YYMMDD) 70000 (HHMMSS)

Time factor: 1.002   Band usage: 1.726%   Threshold: –112dBm

Median Message Length: 2.003   Mean Message Length: 2.679   Total Number of Messages: 2111

Figure 13. Measurement results for a 1-hr time period when the traffic is noticeably lower during the day (Chicago, Illinois site).



Measurement Location: Chicago   Channels 7 – 97

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz   End Freq.: 161.572 MHz

RBW: 30kHz   Detector: Sample   Sweep time: 0.62 Sec.   Points: 1001

Data Directory: F:\DATA\

First record: F:511 R:110   Number of records: 3581

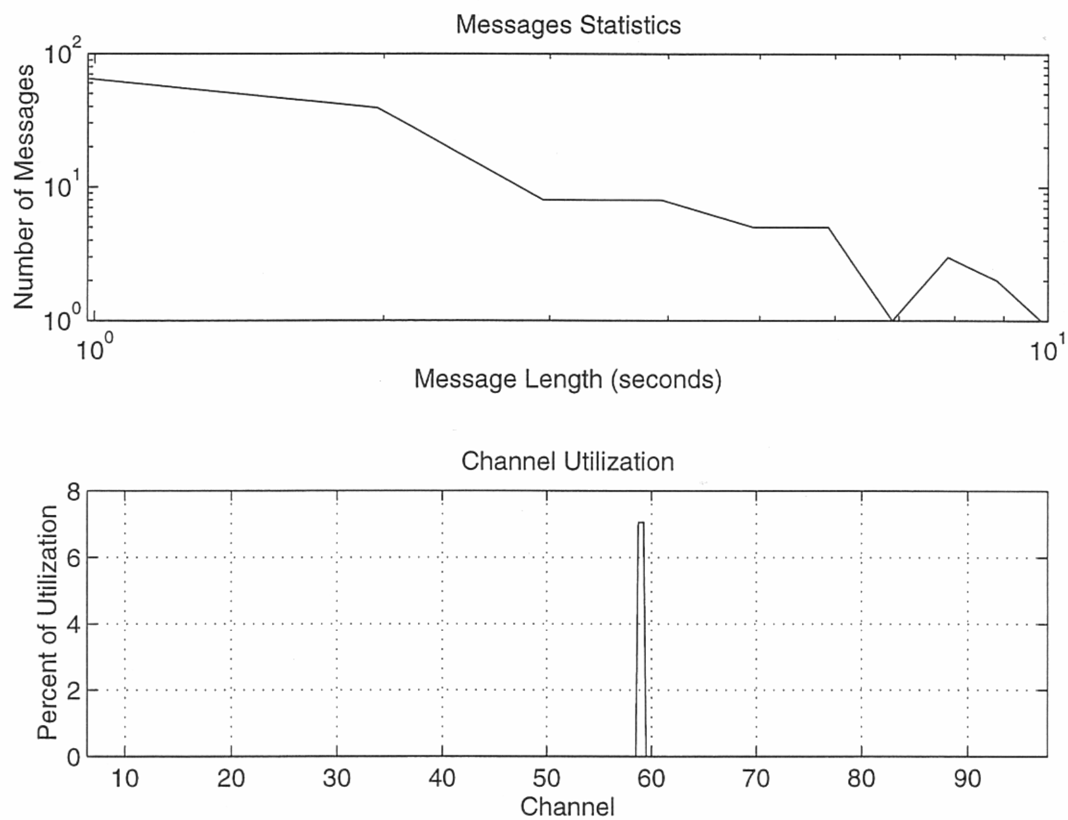
Measurement Start: 960816 (YYMMDD) 90000 (HHMMSS)

Measurement End: 960816 (YYMMDD) 100000 (HHMMSS)

Time factor: 1.005   Band usage: 4.797%   Threshold: –112dBm

Median Message Length: 2.011   Mean Message Length: 3.05   Total Number of Messages: 5152

Figure 14. Measurement results for a 1-hr time period when the traffic is noticeably higher during the day (Chicago, Illinois site).



Measurement Location: Chicago Channel: 59 161.0100 MHz

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz End Freq.: 161.572 MHz

RBW: 30kHz Detector: Sample Sweep time: 0.62 Sec. Points: 1001

Data Directory: F:\DATA\

First record: F:22 R:78 Number of records: 3660

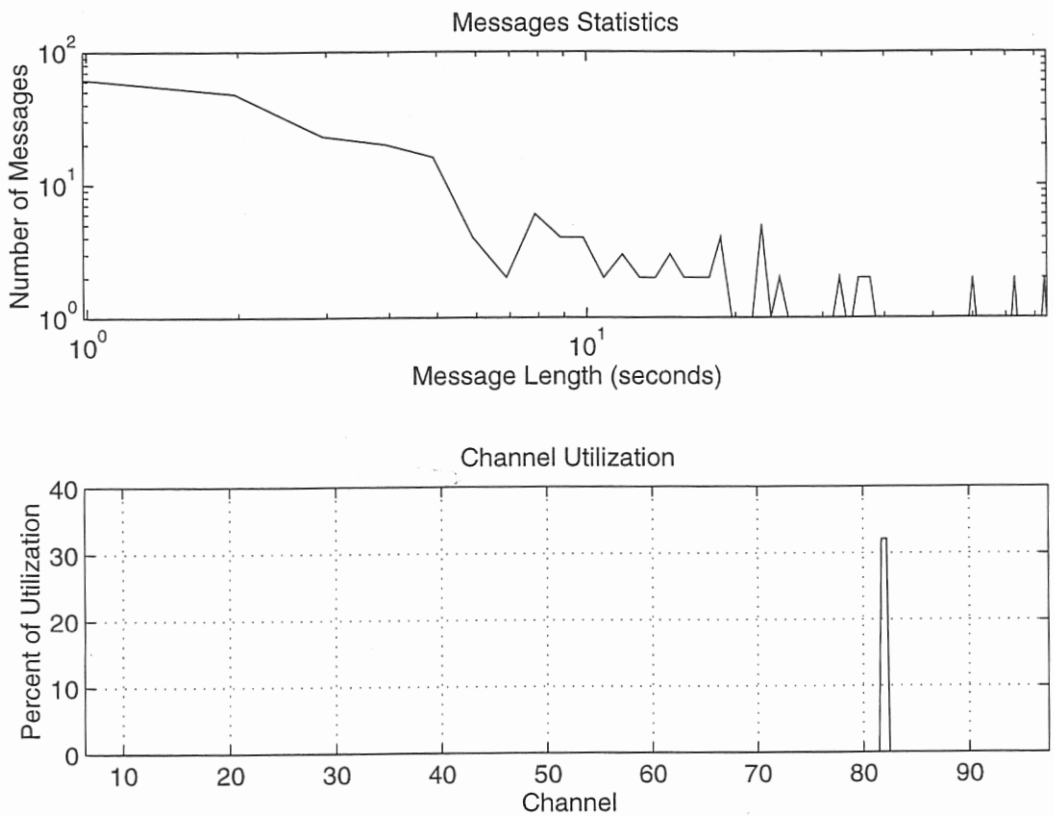
Measurement Start: 960814 (YYMMDD) 170000 (HHMMSS)

Measurement End: 960814 (YYMMDD) 180000 (HHMMSS)

Time factor: 0.9836 Band usage: 7.049% Threshold: −112dBm

Median Message Length: 0.9836 Mean Message Length: 1.998 Total Number of Messages: 127

Figure 15. Measurement results showing an example of a channel carrying data traffic.



Measurement Location: Chicago   Channel: 82 161.3550 MHz

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz   End Freq.: 161.572 MHz

RBW: 30kHz   Detector: Sample   Sweep time: 0.62 Sec.   Points: 1001

Data Directory: F:\DATA\

First record: F:22 R:78   Number of records: 3660

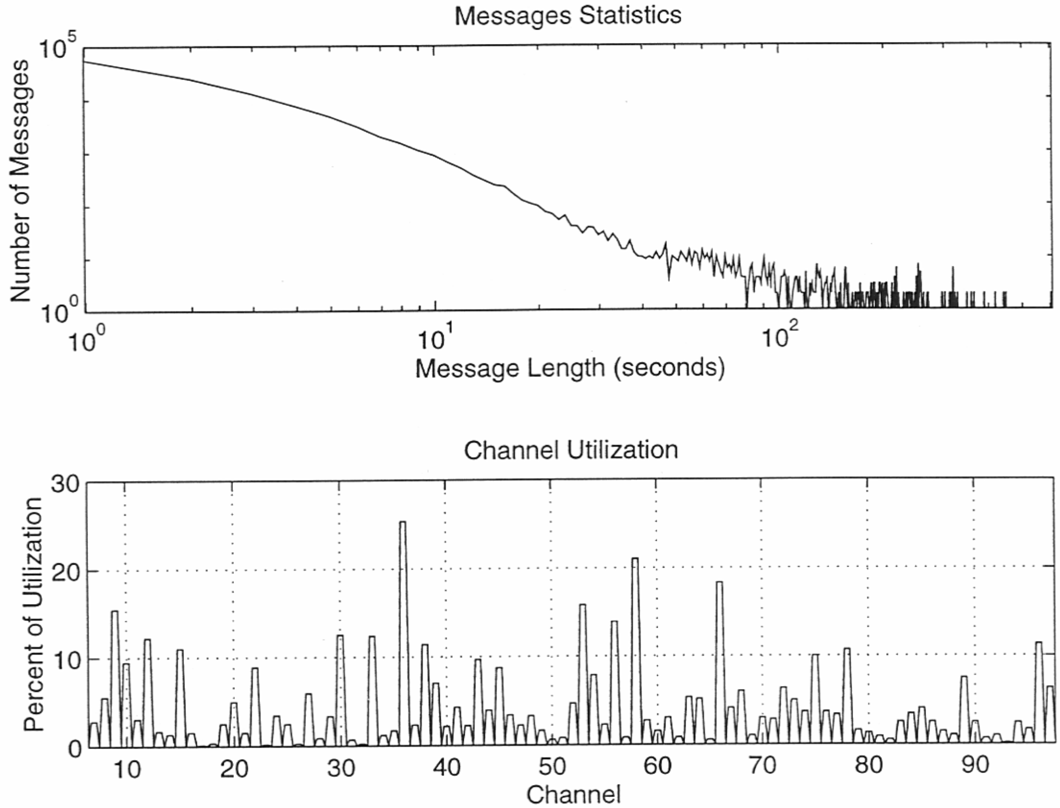
Measurement Start: 960814 (YYMMDD) 170000 (HHMMSS)

Measurement End: 960814 (YYMMDD) 180000 (HHMMSS)

Time factor: 0.9836   Band usage: 32.1%   Threshold: –112dBm

Median Message Length: 1.967   Mean Message Length: 5.665   Total Number of Messages: 204

Figure 16. Measurement results showing an example of a channel carrying voice traffic.



Measurement Location: Kansas City   Channels 7 – 97

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz   End Freq.: 161.572 MHz

RBW: 30kHz   Detector: Sample   Sweep time: 0.62 Sec.   Points: 1001

Data Directory: F:\DATA\

First record: F:1 R:1   Number of records: 8.64e+004

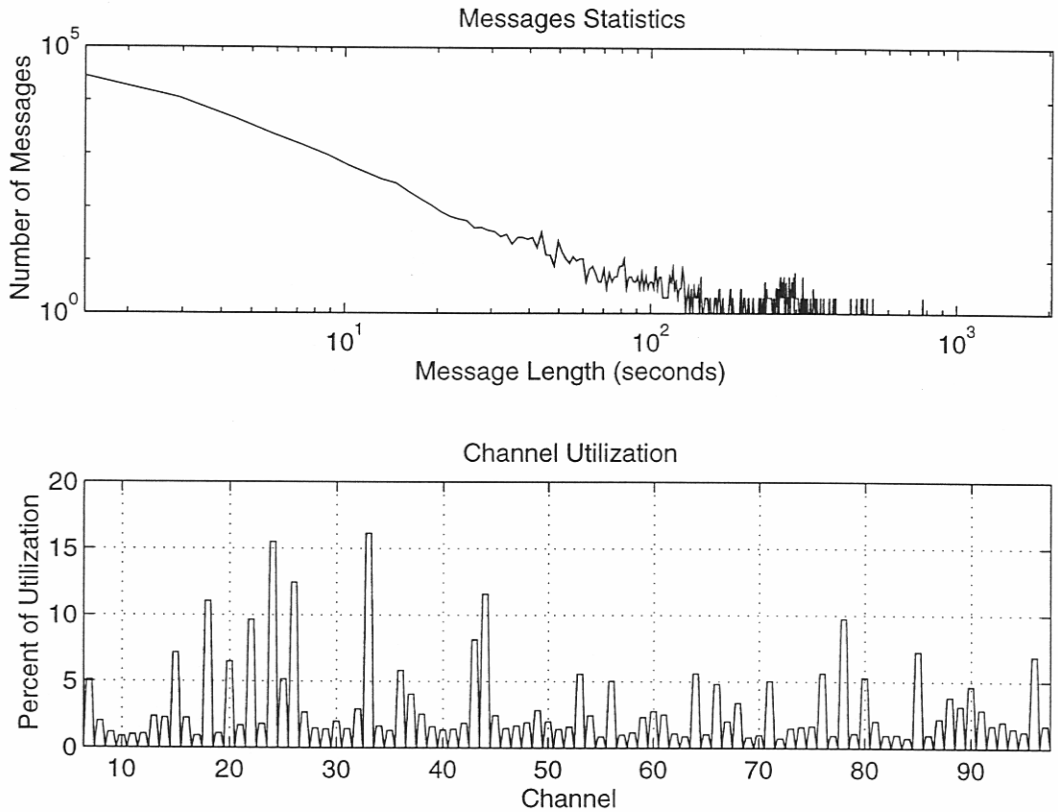
Measurement Start: 960612 (YYMMDD) 113343 (HHMMSS)

Measurement End: 960613 (YYMMDD) 112604 (HHMMSS)

Time factor: 0.9947   Band usage: 4.766%   Threshold: –114dBm

Median Message Length: 1.989   Mean Message Length: 3.17   Total Number of Messages: 1.176e+005

Figure 17. Measurement results over a typical day's worth of activity at the Kansas City, Missouri site.



Measurement Location: Saint Louis Channels 7 – 97

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz End Freq.: 161.572 MHz

RBW: 30kHz Detector: Sample Sweep time: 0.62 Sec. Points: 1001

Data Directory: F:\DATA\

First record: F:1 R:1 Number of records: 5.474e+004

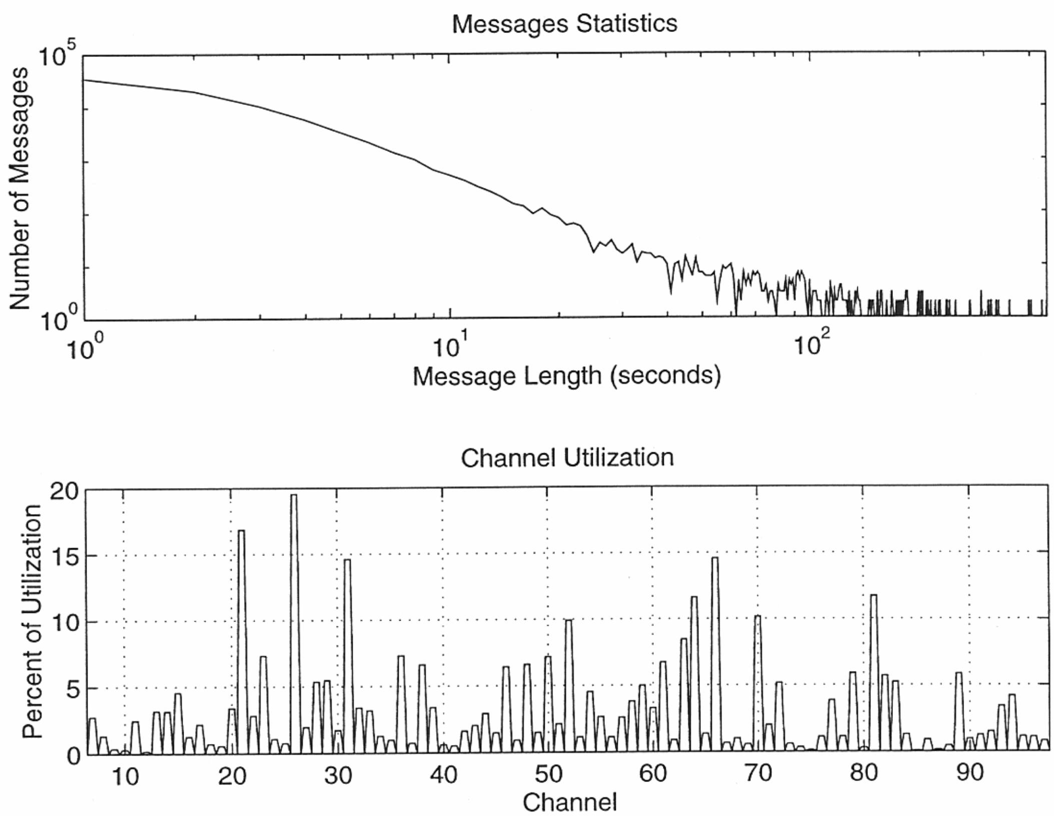
Measurement Start: 960723 (YYMMDD) 125837 (HHMMSS)

Measurement End: 960724 (YYMMDD) 111341 (HHMMSS)

Time factor: 1.463 Band usage: 3.274% Threshold: −111dBm

Median Message Length: 1.463 Mean Message Length: 4.578 Total Number of Messages: 5.213e+004

Figure 18. Measurement results over a typical day's worth of activity at the Saint Louis, Missouri site.



Measurement Location: Chicago   Channels 7 – 97

Measurement type: Swept Spectrum

Beg. Freq.: 160.208 MHz   End Freq.: 161.572 MHz

RBW: 30kHz   Detector: Sample   Sweep time: 0.62 Sec.   Points: 1001

Data Directory: F:\DATA\

First record: F:1 R:1   Number of records: 8.178e+004

Measurement Start: 960814 (YYMMDD) 161442 (HHMMSS)

Measurement End: 960815 (YYMMDD) 145720 (HHMMSS)

Time factor: 0.9997   Band usage: 3.52%   Threshold: –112dBm

Median Message Length: 1.999   Mean Message Length: 3.132   Total Number of Messages: 8.362e+004

Figure 19. Measurement results over a typical day’s worth of activity at the Chicago, Illinois site.

3.3 Spectrum Usage Comparison

Although there have been several Federal Communications Commission (FCC) studies [1-4] that have investigated land mobile spectrum utilization, none of them have surveyed and characterized the traffic in the 160.215- to 161.565-MHz band as in-depth as this survey has done. The way in which the data were measured in the earlier studies and the emphasis of the studies was much different than the survey done for this report. However, we did compare data taken during the previous studies with those taken during this study (Table 1 and Table 2).

There are differences in the ways the data were obtained and analyzed in the previous studies versus this study. In the previous studies, channels were monitored as a block of frequencies continuously for a 5-min period then not monitored while two other blocks of frequencies were monitored. Thus, a group of channels would be monitored for 5 min during a 15-min period. The frequencies were monitored for two days per site and only between the hours of 8:00 A.M. and 6:00 P.M. The peak hour transmission occupancy for the FCC was determined by the 90th percentile occupancy[2] of the 5-min occupancies for each channel and is shown in Tables 1 and 3 below. By contrast, the peak hour transmission occupancy for this study was determined by the peak band usage for a 1-hr period and is shown in Tables 2 and 4 below. All the tables show the number of channels that have a certain percent usage.

[2] "90th Percentile Occupancy: This occupancy statistic characterizes peak usage on a channel defined as the five-minute occupancy value exceeded by only 10% of all five-minute values... [The 90th Percentile Occupancy was used because] it requires fewer samples per hour for comparable accuracy... [and] peak usage period[s] occurred during different hours each day... [The 90th Percentile Occupancy was found to have] excellent statistical correlation between Peak Hour and 90th Percentile Occupancies. The parameters are roughly equivalent in characterizing peak usage."[2]

Table 1. Survey Comparisons Showing the Number of Channels Having a Given Percent Usage (90th percentile occupancy) [1-4]

Site Location	Percent Usage									
	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
Detroit Belle Island	75	10	4	2	-	-	-	-	-	-
Detroit Galinee Park	83	5	3	-	-	-	-	-	-	-
Detroit Oakland Community College	79	6	2	4	-	-	-	-	-	-
LA Griffith Park	36	17	18	7	1	3	3	3	1	2
LA Rose Hill Memorial Park	60	10	11	1	3	2	2	1	1	-
LA Orange Hill Restaurant	72	5	5	3	2	1	2	1	-	-
LA Torrance Airport	68	8	5	2	2	2	1	-	2	1
San Diego Grosmont College	86	2	-	1	-	1	-	-	1	-
San Diego Montgomery Field	84	4	-	-	2	-	1	-	-	-
San Diego Point Loma	83	3	1	1	1	1	1	-	-	-
Washington D.C. University of Maryland, Fort Myer	75	12	3	1	-	-	-	-	-	-

Table 2. Survey Comparisons Showing the Number of Channels Having a Given Percent Usage (busy hour).

Site Location	Percent Usage									
	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
Saint Louis	57(24)*	9	1	-	-	-	-	-	-	-
Kansas City	67(0)*	14	4	4	1	1	-	-	-	-
Chicago	65(15)*	7	-	3	-	1	-	-	-	-

*The numbers in the parenthesis are channels with exactly zero usage during the busy hour.

In the FCC reports, several usage groups were categorized to subjectively quantify the measured channel usage. They defined a mobile channel with measured usage of 40-100% (or 60-100%) during the 90th percentile 5-min period to have "Very High Usage," 16-39% (or 24-59%) to have "Substantial Usage," and 0-15% (or 0-23%) to have "Low Usage." Those with exactly 0% usage are noted as "Zero." The results of the groupings for the FCC surveys and the present survey are given in Table 3 and 4, respectively.

The tables show that in the 20 years since the FCC surveys, the most change has been an increase in traffic that resulted in reduction of channels with zero usage and an increase of channels with low usage. The majority of the channels still do not fall into the "Very High" or "Substantial Usage" groupings.

Table 3. Survey Comparisons Showing the Number of Channels Within Various Usage Groups (90th percentile occupancy) [1-4]

Site Location	Zero	Low (0-15%)	Substantial (16-39%)	Very High (40-100%)
Detroit	-	79	12	-
	Zero	Low (0-23%)	Substantial (24-59%)	Very High (60-100%)
LA	27	19	33	12
San Diego	57	27	3	4
Washington D.C.	53	30	8	-

Table 4. Survey Comparisons Showing the Number of Channels Within Various Usage Groups (busy hour)

Site Location	Zero	Low (0-15%)	Substantial (16-39%)	Very High (40-100%)
Saint Louis	24	64	3	-
Kansas City	0	74	15	2
Chicago	15	68	7	1
	Zero	Low (0-23%)	Substantial (24-59%)	Very High (60-100%)
Saint Louis	24	66	1	-
Kansas City	0	85	5	1
Chicago	15	72	4	-

4. CONCLUSION

Spectrum utilization measurements were made in the frequency range from 160.215- to 161.565 MHz; this band is exclusively assigned to the railroad land mobile radio service. Each of the channels is 15-kHz wide. Three different sites were surveyed; these sites were expected to have high radio traffic and to allow for varying conditions such as the different types of traffic over the channels, propagation environments, line-of-sight conditions, and electromagnetic interference. The spectrum usage surveys spanned two states and three cities. The measurements were made to determine the usage of each channel over 24-hour periods, to evaluate diurnal variations, and to determine message length statistics.

Significant findings are:

1. From observations made at the measurement sites, there appear to be four categories of usage:

    - Voice—dispatch channels had high measured usage (about 40% on some channels during a busy hour).
    - Voice—telephone interconnect channels also had high measured usage (about 40% on some channels during a busy hour).
    - Voice—point-to-point communication channels had moderate measured usage (usually between a few percent to 20% over a 24-hour period).
    - Data channels had low measured usage (around 5% during the busy hour).

2. Typical results at three railroad measurements sites for 91 channels in the 160.215- to 161.565-MHz railroad-land-mobile-radio-service band include:
   - 60,000-130,000 messages per 24-hour period.
   - 2,000-7,000 messages per hour.
   - Diurnal variation of three to four fold increase between least and most busy hour.
   - Median message length of 2 s.

At all three measurement locations, characteristics of the message length statistics were similar. The message lengths of different channels (voice, data, or mixed) all had a large number of short messages (1 to 2 s long) such that the median message length was usually around 2 s long. At all three sites, the message length statistics could be approximated by a straight line when plotted on a log-log scale. The fraction of messages versus message length could be approximated by the following probability density function:

$$y=A\,/\,(C+x^{B})$$

where: x is the message length in seconds (discrete),
y is the fraction of messages with length X; and
A = 1.46, B = 2.31, C = 1.99.

Voice channels with dispatch and telephone interconnect traffic seem to have the most usage. For these channels, one person may be the primary communicator on the channel, and that person is the one that is controlling the traffic. For dispatch or telephone interconnect cases, it seems reasonable that the channel would show relatively high usage. The data channels do not appear to be used as much as the voice channels. Since data channels are expected to be able to carry up to about 40-50% loads without major performance problems, these channels have much room for growth.

Typical results over all 91 channels varied from between about 2000-7000 messages per hour and between about 60,000-130,000 messages per day. Diurnal variations show approximately a three to four fold difference between the busy hour and the least busy hour. Many of the channels show usage above 1% over a 24-hour period, with some channels showing over 50% usage during a 1-hr period. In the telephone industry, a maximum blockage of 1% is engineered for their systems during the busiest time of year. Blockage means that a person who tries to make a call cannot complete the call because the communication network is busy and cannot handle another call. For the radio system used by the railroad industry, blockage by 50% or more may be somewhat acceptable since the person trying to use the channel may be able to wait for the channel to clear, or use another channel.